Claims

We claim:

1. A light-emitting device, comprising:

an active region configured to generate light in response to injected charge; and

a tunnel junction structure located to inject charge into the active region and including an n-type tunnel junction layer of a first semiconductor material, a p-type tunnel junction layer of a second semiconductor material and a tunnel junction between the tunnel junction layers, the first semiconductor material including gallium (Ga), nitrogen (N), arsenic (As) and a Group VI dopant.

2. The light-emitting device of claim 1, in which the n-type tunnel junction layer is located between the p-type tunnel junction layer and the active region.

3. The light-emitting device of claim 1, in which the p-type tunnel junction layer is disposed between the n-type tunnel junction layer and the active region.

4. The light-emitting device of claim 1, in which the Group VI dopant is chosen from sulfur (S), selenium (Se) and tellurium (Te).

5. The light-emitting device of claim 4, in which the first semiconductor material consists essentially of gallium indium nitride arsenide $Ga_{1-x}In_xNAs$ in which $x \geq 0$.

6. The light-emitting device of claim 1, in which the second semiconductor material includes gallium, nitrogen, arsenic and antimony.

7. The light-emitting device of claim 5, in which:

an electromagnetic field intensity distribution exists in the light-emitting device; and

the tunnel junction is located at a minimum in the electromagnetic field intensity distribution.

8. The light-emitting device of claim 1, in which:

the first semiconductor material consists essentially of gallium indium nitride arsenide GaInNAs; and

the second semiconductor material consists essentially of gallium nitride arsenide antimonide GaNAsSb.

9. The light-emitting device of claim 8, in which:

the first semiconductor material consists essentially of gallium indium nitride arsenide $Ga_{1-w}In_w N_x As_{1-x}$, in which $w \leq 0.4$ and $x \leq 0.15$; and

the second semiconductor material consists essentially of gallium nitride arsenide antimonide $GaN_yAs_{1-y-z}Sb_z$ in which $y \leq 0.15$ and $z \leq 0.3$.

10. The light-emitting device of claim 1, structured to generate light having a wavelength between 620 nm and 1650 nm.

11. The light-emitting device of claim 1, in which the second semiconductor material comprises at least one of indium, antimony and bismuth.

12. A method of making a tunnel junction structure, the method comprising:

providing a substrate;

forming over the substrate an n-type tunnel junction layer of a first semiconductor material, the first semiconductor material including gallium (Ga), nitrogen (N), arsenic (As) and a Group VI dopant; and

forming over the substrate a p-type tunnel junction layer of a second semiconductor material juxtaposed with the n-type tunnel junction layer to form the tunnel junction.

13. The method of claim 12, in which:

the second semiconductor material comprises gallium and two or more of nitrogen, arsenic, antimony and bismuth; and

the method additionally comprises doping the second semiconductor material p-type.

14. The method of claim 12, further comprising:

doping the first semiconductor material n-type using a Group VI dopant chosen from sulfur (S), selenium (Se) and tellurium (Te).

15. A method for generating light, the method comprising:

forming an optical cavity;

locating an active region in the optical cavity, the active region configured to generate light in response to injected current;

forming a tunnel junction structure located to inject charge into the active region, including:

forming an n-type tunnel junction layer of a first semiconductor material including gallium (Ga), nitrogen (N), arsenic (As) and a Group VI dopant and

forming a p-type tunnel junction layer of a second semiconductor material juxtaposed with the n-type tunnel junction layer to create a tunnel junction; and

injecting current into the active region using the tunnel-junction structure.

16. The method of claim 15, in which the active region is configured to generate light having a wavelength between 620 nm and 1650 nm.

17. The method of claim 15, in which the Group VI dopant is chosen from sulfur (S), selenium (Se) and tellurium (Te).

18. A tunnel junction structure, comprising:

an n-type tunnel junction layer of a first semiconductor material including gallium (Ga), nitrogen (N), arsenic (As) and a Group VI dopant;

a p-type tunnel junction layer of a second semiconductor material; and

a tunnel junction between the tunnel junction layers.

19. The tunnel junction structure of claim 18, in which the Group VI dopant is chosen from sulfur (S), selenium (Se) and tellurium (Te).

20. The tunnel junction structure of claim 18, in which the first semiconductor material consists essentially of gallium indium nitride arsenide $Ga_{1-x}In_xNAs$ in which $x \geq 0$.

21. The tunnel junction structure of claim 18, in which the second semiconductor material comprises gallium and two or more of nitrogen, arsenic, antimony and bismuth.

22. The tunnel junction structure of claim 18, in which:

the first semiconductor material consists essentially of gallium indium nitride arsenide (GaInNAs); and

the second semiconductor material consists essentially of gallium nitride arsenide antimonide (GaNAsSb).

23. The tunnel junction structure of claim 22, in which:

the first semiconductor material consists essentially of gallium indium nitride arsenide $Ga_{1-w}In_wN_xAs_{1-x}$, in which $w \leq 0.4$ and $x \leq 0.15$; and

the second semiconductor material consists essentially of gallium nitride arsenide antimonide $GaN_yAs_{1-y-z}Sb_z$ in which $y \leq 0.15$ and $z \leq 0.3$.